

## Article by Alexander Graham Bell, undated, with transcript

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### Upon "The Conservation of Energy".

The doctrine of "The Conservation of Energy", is a generalization of the very highest order; for it brings together under one hypothetical law, phenomena of the most widely different kind. By it we are taught that "Energy", like matter, can neither be created nor destroyed, so that the total amount of "Energy" in the universe is a constant quantity, incapable of increase, or diminution.

In any limited system of bodies, the energy of the system cannot be changed by the mutual action of the bodies themselves. Such a system may lose "Energy" by transferring it to other systems, or gain it at the expense of outside bodies, but in every case of transference the energy lost by one system is gained by another, so that the energy as a whole is conserved.

What then is "Energy"? And how is it manifested to the senses? ¶The latter query is much more easily answered than the former. It is through motion that energy is perceived by the senses.

A mass of matter may have a movement of translation as a whole, or the parts of the mass may move relatively to one another, while the mass as a whole remains at rest. In either case the particles of the mass are in motion, and the body is said to possess "energy". Motion is indeed the soul of "Energy", without which it cannot manifest its existence. Wherever there is "Motion", there is "Energy", and the amount of actual "energy" is measured by the amount of "Motion". It is proportionately to one half of the product of the mass into the square of its velocity, or  $E = MV^2$  or:  $E = \frac{MV^2}{2}$

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Let us glance for a moment at the mode by which apparent destruction of motion is explained.

When two equal masses of lead come into collision, with equal and opposite velocities, both masses come to rest. What has become of their motion? How has “Energy” been conserved? [???] In such a case, we observe that the bodies have become hot. Indeed in every such case heat appears after impact, that was not in existence before; and motion disappears that was. The heat is thus perceived to be the equivalent of the lost vis-viva. [???] The discovery that a definite mass amount of mass-motion, when arrested, always gives rise to a definite amount of heat — under similar conditions of [???] experiment — forms the basis upon which has been built the doctrine of the “Conservation of Energy”. The mechanical equivalent of heat has been independently determined by different investigators, by distinct methods of research — and the results obtained are so remarkably concordant as to demonstrate the fact that heat in matter is motion of some kind going on in the mass. The parts of the mass continued in motion relatively to one another after although the mass as a whole has come to rest.

Let us look at this matter a little more closely. We know that lead can be compressed into a smaller volume by the application of suitable pressure — from which we infer that it is porous to a certain extent — like a sponge.

Other considerations also lead us to the elusion conclusion, that lead, and other substances are in reality organized systems of material particles separated by empty spaces. We are thus brought to consider each mass of lead as composed of an army of particles marshalled in ranks according to some definite plan of organization. [???] Before impact Heading Collision between two masses of lead. the individual particles in each mass have a common motion in the same direction, so that the armies as wholes advance against one another.

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Collision results in what may be termed a disastrous rout e , in which both armies are defeated, The particles of the each mass run hither and thither, and the organized armies become panic-stricken mobs. The individual particles may still be in the most active motion, but as they rush about in all sorts of directions without combined action-the armies as wholes have come to rest. The masses of lead co re ntain the same amoont of energy after collision as before, but the form of motion has been changed from the simple motion of translation, into the complex motion of heat.

The character, or nature of the internal motions going on in a mass will depend upon the character, or nature of the molecular structure of the substance , or-to pursue our simile — upon the nature of the organization of our army. ¶We may, for example, suppose our army to be composed of regiments and battalions, and companies of particles. It is obvious that the individuals in each company may change places, and move about in very many different mays, and yet the companies as wholes, be stationary upon the same ground. The companies may march backwards and forwards over a limited space, and yet the battalions of which these y form a part may continue to occupy the same field , &c etc . ¶Many 4 different manoeuv ers res may be simultaneously executed by different sections of the army; some moving at a slow march; others charging at full speed; while still others may form themselves into squares, or march in a circle. All sorts of internal movements may be going on, and yet the army, as a whole, may remain stationary upon the same field of operations, occupying continuously the same space of ground.

The individual particles composing a mass of matter are too minute for us ever to hope to observe them directly; but we can perceive through various agencies, the grand movements of the regiments, and battalions, and companies. ¶Some of the manoeuvres executed by our microscopic army, give rise in us to distinct sensations, while others can be directly observed as motion.

Thus heat[???]light, and sound are some of the sensations produced, while the quivering motions going on in a mass of jelly, or on the surface of water, can be clearly perceived as motion by the eye, and the sense of touch.

There may be many other forms of motion than those which produce heat, light, sound or tangible tremor, which elude direct observation, on account of lack of senses by which we to perceive them. We have, for instance, no electrical or magnetical sense by which to detect the presence of the kind of motion characterizing electricity, or magnetism; nor do the molecular movements occurring during chemical reactions originate specific sensations. It may be possible that odor and taste correspond to some form of motion in matter, but of this we cannot yet be sure.

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Whatever may be the character of the complex movements that give rise to specific sensations, we may be sure that the ultimate particles of a mass are animated only by a movement of translation. So far as they are concerned there is only one form of motion possible — simple translation in space. The different manoeuvres executed by our microscopic army all result from differences of direction in the movements of the individual particles. When all are animated by a common motion in the same direction, the mass as a whole thereby acquires a movement of translation. When they move in different directions, the mass may be stationary, but the particles separate from one another, so that the mass as a whole expands. If a limit is set to the expansion, as in the case of a solid, or of a confined gas, the movements partake of the nature of vibrations.

¶If a particle continues moving within a limited area, it can only do so by doubling on its path, and it therefore, necessarily, describes some form of vibration. It may move backwards and forwards in a straight line, or this oscillation may be expanded into an elliptical or circular path, or into one shaped like the figure 8, or any of the other well known figures produced by sounding bodies; or one particle may revolve around another; or may wander from one end of the whole mass to the other. In any case the internal

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movements of a body, whose expansion is limited, necessarily partake of the nature of vibrations. ¶¶The difference between rectilinear and vibratory motion is simply a difference relating to direction. In the former case the direction is constant, in the latter it is not, but on the contrary becomes alternately plus and minus . When therefore we “convert motion 6 into heat” by the collision of non-elastic masses, we do not thereby mean that “motion” has been destroyed, and another thing , “heat” , created as an equivalent. We mean simply that the motion s of the particles of the bodies, has been changed in direction, just as the direction of the motion of a billiard ball may be changed by the impact of another ball. No motion has been destroyed, it has only been changed in direction. ¶¶It is unfortunately that we use the words “heat”, “light”, “sound”, &c, in a dual sense. It would perhaps be better, in order to avoid confusion of thought to assign these words only to the sensations produced, and to designate the causes as “vibrations” or “motions”. In the case of electrical and other effects a similar mode of expression would at once designate the supposed cause as distinct from the effect. Thus “heat vibrations” or “motions” would designat e those kind s of vibrations or motions that produce the sensation s ” of heat; “electrical vibrations” or ““motion h ” those concerned in the production of electrical phenomena; and “chemical motions” or “vibrations” those occurring during chemical re-actions.

Some confusion of thought might still however result from the fact that the self-same vibration or motion may produce more than one sensation or effect. For instance; sound-vibrations may be felt as tangible tremor; light-vibrations may also be perceived as heat; electrical-motions involve magneti l c al effects; and chemical-motions produce thermal, electrical, and other effects.

The word “tremor” might perhaps be used as a generic term, to 7 distinguish the vibrations motion of the parts of a body as a from that of the whole. For instance; we may say that arrested mass-motion produces “tremor”, and, to my mind, this is more satisfactory than to say it produces “heat”, or “sound” or any specific form of internal motion; for I in several some cases, all forms of tremor-motion might be simultaneously produced ; and the self-same tremor may give rise to more than one sensation or effect. ¶¶ ( Tremor , in a

mass , produces tremor in surrounding matter ; and the tremor-motions are propagated radially from the centre of disturbance in the t f orm of waves. Thus sound-vibrations are propagated through air and other substances to the ear, and light-vibrations through the luminiferous medium. We can hardly doubt that tremors of all sorts / give rise to waves in the luminiferous medium, although we may not have senses by which to detect their presence. Thus those chemical-vibrations, which are at the same time light-vibrations are propagated to the eye in such a manner as to produce characteristic lines in the spectrum; and but we have evidence of the existence of radiant energy in the invisible part of the spectrum beyond the violet, capable of producing chemical re-actions. So, too, the fact of electrical induction points to the propagation of electrical-motions radially through some medium; and the velocity of the propagation of electrical induction corresponds so closely to the velocity of the propagation s of light-vibrations that we can hardly doubt that the luminiferous medium itself plays some part in tha production of the phenomena. )

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Whatever idea we may form of the nature of the ultimate constitution of matter, impenetrability must be accepted as a fundamental property; F or resistance of to compression seems to be a characteristic common to all matter. ¶For example;-A piston moving air-tight in a hollow cylinder closed at the bottom cannot be made to touch the bottom so long as there is matter of any kind between. The resistance to compression increases as the volume of the substance is diminished, but however great the compressing power may be, the volume of the substance never reaches zero. However much this increase of resistance may be due to motion among the particles of the substance, it is obvious that the resistance itself is not due to the motion; for motion abstractly considered is a mere idea, and has no real existence. Whereever there is motion, it is matter that moves, and to the real existence “matter” we must credit the resistance. The fact that this matter opposes an insuperable obstacle to the advance

of the piston shows that the substance of the matter is absolutely impenetrable , From which we may conclude that compressibility results from the presence of pores or empty spaces in the mass; and that resistance to compression when the parts are not in contact , varies arises from the vibration or motion of the parts among themselves. This experiment which shows that the particles of a mass are impenetrable, also indicates that such particles continue in motion in spite of collision with one another and with the sides of the cylinder. Elasticity then is not necessary to “rebound”. “Impenetrability” and “elasticity” involve opposite ideas. “Impenetrability” involves “incompressibility” but “elasticity” involves “compressibility” and a tendency to recovery of shape. Elasticity, then, is a property of porous matter which contains pores . It is a property of complex matter consisting of impenetrable parts separated by empty spaces ; and recovery of shape after compression is due to the motion of these parts. That is to say;— elasticity itself is due to the rebound of non-elastic parts. The idea that rebound is due to elasticity, arises from the notion, that motion is destroyed when non-elastic masses come into collision, but this is not so. Both in the case of elastic, and non-elastic bodies, the particles of which they are composed rebound upon collision; but in the one case, the particles acquire after collision a common motion in a new direction; in the other they do not. In the one case therefore the masses themselves rebound; in the other they remain stationary in a state of tremor .

The numerous experiments that have been made to determine the equivalents of the various forms of motion all demonstrate the retention of motion, in spite of collision, by particles that are themselves impenetrable, and therefore non-elastic. The very fact of mutual equivalence, points to the retention of vis-viva by the particles. Theory points to the same conclusion.

**Heading Start on new page The behavior of simple matter under circumstances of collision, theoretically considered.**

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Particle of simple matter, whether we consider them (1) as material 10 points, on (2), as masses of impenetrable matter devoid of pores, must rebound upon collision . , (if the doctrine of the conservation of energy is true). ¶ This result is independent of any assumption regarding the size of the ultimate particles of matter, and independent of hypotheses concerning attractive or repulsive forces acting in an occult manner. The real behavior of the bodies would of course be a resultant of all the causes concerned. In treating therefore of the purely mechanical action of the masses upon one another, we may ignore the action of occult forces. These may be considered separately, and, if such forces exist, the effects may be super-posed (so to speak) upon the mechanical effects.

(1) LaPlace says;— “The most simple case of equilibrium between several bodies it is that of two material points meeting each other with equal and opposite velocities. Their velocities will be destroyed, and the points reduced to a state of rest by their material mutual impenetrability ” &c.

But such a result is inconsistent with the doctrine of the conservation of energy, which asserts that the energy after collision must be the same as before. Heat-vibration cannot be produced in a body that contains no parts which could be set in a state of tremor. A material point can have no other kind of motion than that of simple translation in space. It cannot even rotate about an axis , for this involves the motion of one point around another. It cannot be compressed, or distorted in shape for it has no shape. It is therefore 11 not elastic. It is the material equivalent of a mathematical point, and we cannot therefore conceive of it as a real existence. But if such points exist, they must rebound from one another, for the energy after impact must be the same as before.

(2) Sir Isaac Newton 2 says;— “Bodies which are either absolutely hard, or so soft as to be void of elasticity, will not rebound from one another. Impenetrability makes them only stop. If two equal bodies meet directly in vacuo they will by the laws of motion stop where they



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meet and lose all their motion , and remain in rest, unless they be elastic, and receive new impulse from their spring” &c.

In the light of the conservation of energy we can no longer hold this statement to be strictly true. We now know that bodies that stop when they meet, do not lose all their motion. On the contrary the parts of which they are composed go on moving with the same energy as before, giving rise to heat-vibration s.

(Note A Page 54 in note book.)

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On account of impenetrability matter cannot move into space that is already occupied by other matter, so that a blow upon one end of a mass of impenetrable matter devoid of pores cannot result in the motion of the part struck without at the same time moving the whole mass in front of it. ¶¶If therefore two equal masses of impenetrable matter devoid of pores should collide with equal and opposite velocities the masses must either come absolutely to rest (which is inconsistent with the doctrine of the conservation of energy), or they must rebound with such velocities as to make the energy after impact the same as before.

The thought occurs that in any case the bodies must stop before they rebound. What then becomes of their energy during the time they are at rest? How long will they remain at rest? And if they remain at rest for any time at all, why should they rebound? Would not this mean creation of motion? It would; but if they remain at rest for any time at all, their motion has been destroyed, which is equally inconsistent with the conservation of energy. The duration of their contact therefore cannot be measured in time. The moment of contact is a mere point of time without duration. In this case their motion is no more stopped than if they had gone on without collision; for at any point of time the universe itself is at rest. ¶¶This instantaneous reversal of motion is opposed to our experience with ordinary masses of complex matter containing pores; for in all such cases time is an element in

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changing the amount of direction of motion. Such a body, because it is compressible, goes on moving for a certain time after contact has been established, and is compressed by collision. When the first layers of particles come into contact, the other parts of the body, having empty spaces between them into which they can move, continue to move on account of inertia, so far as they have room, so that it takes time for the effects of collision to be propagated through the mass. But in the case of impenetrable masses devoid of pores, this kind of action cannot take place.

(Go on to note B in notebook 34.) This note not found: De Soul.

The moment the first layer of particles reach contact, the other parts of the bodies are equally arrested, for there are no empty spaces into which they could move. For the same reason each mass must rebound as a whole or not at all, and non-rebound would be inconsistent with conservation of energy.

We cannot look upon this as a case in which a finite velocity has been generated in an infinitesimal portion of time—for no motion has been “generated” at all—it existed before. Nor do I think we are entitled to conclude that motion has been changed in direction—though the masses rebound, for the motion of each mass is continued (in direction) in the other.

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It is rather a case of mutual transfer from one particle to the other, than reversal of the motion of both. The masses rebound—but the motions do not! They persist in the original directions—like waves upon the surface of water. Waves in collision do not rebound, though the particles of water composing them do.

We may then consider rebound as due to a mutual transfer of motion—in which there is no reversal of direction. That this is the true way to look at the case will, I think, appear from mathematical considerations.

Fig. (1)

Let  $M$  (Fig. 1) be a cubical mass of simple matter devoid of pores, having unit length, breadth, and thickness, and let  $M_1$  be another mass of equal cross section. Let these masses impinge upon one another face to face as shown in the diagram. The diagram shows the relative position of the two bodies one second (of time) before contact occurs; and the straight line  $FF_1$  represents the distance between the two opposed faces ( $F$  and  $F_1$ ). This line then represents by its length the rate of approach — or the amount by which the distance which separates them is diminished during each second (of time). Let  $X$  be the point where contact occurs. Then  $FX$  is the distance traversed by  $M$  in unit time, and  $F_1X$  the distance traversed by  $M_1$  in the same time.

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These lines therefore represent the relative velocities of approach of the masses toward one another. That is  $FX = V$  the velocity of  $M$ ; and  $F_1X = V_1$  the velocity of  $M_1$ .

The masses rebound from one another.

Fig. 2.

Fig. 2. represents the relative positions of the bodies — one second after collision — and the line  $FF_1$ , represents their distance apart, one second after collision. Then this line ( $FF_1$ ) represents the rate of recession, or the amount by which their distance apart increases every second (of time).  $XF = U$  the velocity of recession of  $M$ ; and  $XF_1 = U_1$ , the velocity of recession of  $M_1$ .

$V$  or  $V_1$ , (Fig. 1) = rate of approach; and  $U$  or  $U_1$ , (Fig. 2) the rate of recession. The bodies however move in opposite directions so that if the direction of motion of one is considered as plus, that of the other is minus.

Let  $V$  the velocity of approach of  $M$  be considered as in the plus direction. Then  $V_1$ , (the velocity of the approach of  $M$ ) is in the minus direction;  $U$ , (the velocity of recession of  $M$ ) is in the minus direction; and  $U_1$  (the velocity of recession of  $M_1$ ) is in the plus direction.

As the energy of a moving body is measured by the product of the mass into the square of its velocity — the doctrine of 16 the conservation demands of energy demands, that X:—

$$m v^2 + m v^2 = m u^2 + m u^2 \quad (1) \quad m v^2 + m v^2, m u^2 + m u^2, m v^2 + m v^2 = m u^2 + m u^2$$

It is evident that whatever the relative motions of the bodies ( $m m_1$ ) may be, they would not be affected by any common motion of the system ( $m m_1$ ) as a whole. For example:— The same relative motions of the bodies ( $m m_1$ ) would be observed if they were taken on board of a moving railroad train.

In such a case if we desire to note, not their motion relatively to one another, but their motions referred to the earth — we must note the velocity of the train, and the direction of its motion — and compound this constant ( $c$ ) with the motions of the bodies ( $m m_1$ ) so as to produce a resultant.

Call the resultant velocities before collision (referred to the earth)  $V$  and  $V_1$  and the resultant velocities after collision  $U$  and  $U_1$ . Then the Conservation of energy demands that:—

$$(2) \quad m V^2 + m V^2 = m U^2 + m U^2$$

We will consider a case in which the constant motion ( $c$ ) is in a direction parallel to the motions of the bodies — so that the resultant motion of each body (referred to the earth) will be the algebraical sum of the constant ( $c$ ) and the motions of the body.

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Velocities after impact. Fig. 5.

From equation 2 we obtain,

$$m(c+v)^2 + m(c-v)^2 = m(c+u)^2 + m(c-u)^2$$

$$m v^2 + m v^2 + 2c(m v + m v) = m u^2 + m u^2 + 2c(m u + m u)$$

Eliminating equation (1) we obtain

$$(3) \quad m v - m v = m u - m u$$

Add to each side of this equation  $m c$  and  $m c$  then:

$$m c + m c + m v - m v = m c + m c + m u - m u$$

[???]  $m(c+v) + m(c-v) = m(c+u) + m(c-u)$  From which we obtain:—

$$(4) \quad m V + m V = m U + m U$$

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From equations 1 and 2 we obtain,

$$(1) \quad m v^2 - m u^2 = m u^2 - m v^2$$

$$(5) \quad m v + m u = m u + m v,$$

$$[???] \quad v - u = u - v,$$

$$[???] \quad (5) \quad V + V = U + U$$

This is a relation independent of mass. The rate of recession of the bodies ( $m, m$ ) whatever may be their relative masses is always the same as their rate of approach.

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Newtons third law of motion that action and re-action are equal and opposite — from which it follows that  $m v - m, v$ , and  $m u = m, u$ ,

[???]  $m v + m, v, m, u, + m u$

But (3)  $m v - m, v, m, u, - m u$

$m v = m, u$ , and

(6)  $M V = M, V, = M U = M, U$ ,

also

(7)  $V = U V, = U$ ,